Prompt photon production with POWHEG

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18 November 2016

Work done in collaboration with T. Jezo and F. König,
arXiv:1610.02275 [hep-ph], accepted by JHEP

DFG

HELMHOLTZ GEMEINSCHAFT
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References

Recent related publications:

- MK, C. Klein-Bösing, F. König, J.P. Wessels
  How robust is a thermal photon interpretation of the ALICE low-p_T data?
  JHEP 1310 (2013) 119 [arXiv:1307.7034]

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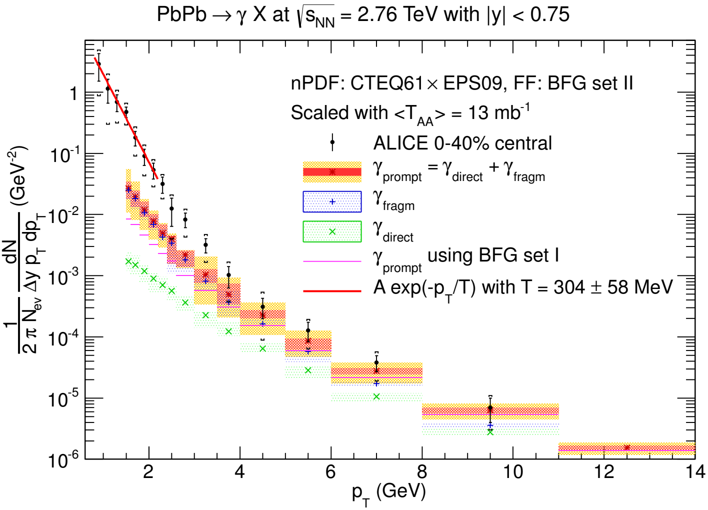
- MK, C. Klein-Bösing, K. Kovarik, G. Kramer, M. Topp, J.P. Wessels
  NLO Monte Carlo predictions for heavy-quark production at the LHC: pp collisions in ALICE
  JHEP 1408 (2014) 109 [arXiv:1405.3083]

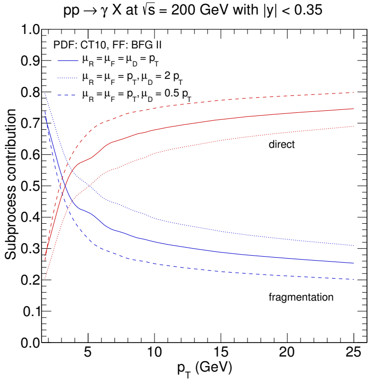
How robust is a thermal photon interpretation ...?

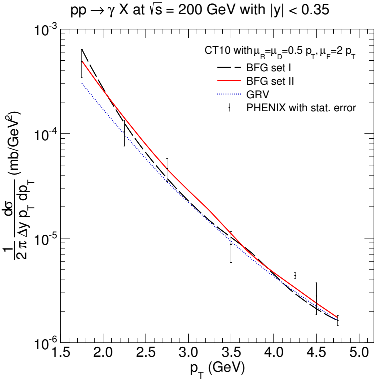
MK., C. Klein-Bösing, F. König, J.P. Wessels, JHEP 1310 (2013) 119



New information on photon fragmentation functions

MK., F. König, Eur. Phys. J. C 74 (2014) 3009





Recalculation of direct processes at NLO

T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.

Leading order:

- Tree-level processes: $q\bar{q} \to \gamma g$, $qg \to \gamma q$
- Also with color and spin correlations (needed for POWHEG)
- Traces with FormCalc 8.4, checked against literature and MG5

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Virtual corrections:

- One-loop processes: $q\bar{q} \to \gamma g$, $qg \to \gamma q$
- Tensor reduction w/ Form, scalar functions w/ LoopTools 2.13
- Renormalization in $\overline{\mathrm{MS}}$, checked against MG5_aMC@NLO

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Real corrections:

- Tree-level processes: $q\bar{q} \to \gamma gg(q\bar{q})$, $qg \to \gamma qg$, $gg \to \gamma q\bar{q}$
- Traces with FormCalc 8.4, checked against MG5
- Dipole subtraction, QCD checked against AutoDipole 1.2.3
- Integrated QED dipole reproduces fragmentation function

Reference calculation and choice of input parameters

NLO calculation: [P. Aurenche et al., Phys. Rev. D 73 (2006) 094007]

- JETPHOX
- Direct and fragmentation contributions

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Renormalization and factorization scales:

- $\mu = \mu_p = \mu_\gamma = p_T^\gamma$
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Photon fragmentation function: [L. Bourhis et al., Eur. Phys. J. C 2 (1998) 529]

- BFG set II

The POWHEG method

P. Nason et al., JHEP 0411 (2004) 040; 0711 (2007) 070; 1101 (2011) 095

NLO calculations:

- Increase normalization, reduce scale dependence (μ, μ_p, μ_γ)
- Include only one additional parton, no hadronization

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- Leading-order normalization, large scale dependence
- Many additional partons, different hadronization models

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NLO+PS with POWHEG:

- Subtract overlap with FKS [Frixione, Kunszt, Signer., Nucl. Phys. B 467 (1996) 399]
- Generate hardest radiation first, only positive weights
- Match to any PS (PYTHIA, HERWIG, ...) with p_T veto

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Required ingredients:

- Color- and spin-correlated squared Born amplitudes
- Finite (UV-renormalized and IR-subtracted) loop amplitudes
- Real emission squared amplitudes

Specific issues for photons

T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.

"Fragmentation" contribution: [S. Höche et al., Phys. Rev. D 81 (2010) 034026]

- QED parton shower ($q \to q\gamma$), matched to NLO direct cont.
- Suppressed wrt. to QCD by α/α_s, color factors, multiplicities
- Globally only 2% photons in total QCD+QED event samples
- Reweight QED radiation by $C{=}50\,(100)$, check independence

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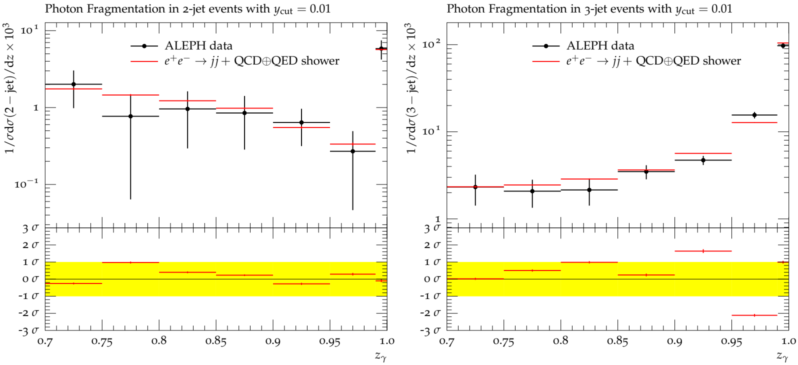
Symmetrization of parton splitting in the final state:

- `doublefsr=1` adds splitting $q \to \gamma q$
- Avoids high-p_T photons with low statistics, but high weights

Photon fragmentation function in 2- and 3-jet events

S. Höche et al., Phys. Rev. D 81 (2010) 034026 (Fig. 1)



Excellent description of ALEPH data [ALEPH Coll., Z. Phys. C 69 (1996) 365]

Works also for other jet resolution parameters $y_{\mathrm{cut}} \geq \min\left(\frac{E_i}{E_j}, \frac{E_j}{E_i}\right) \cdot \frac{s_{ij}}{s}$

Born suppression factor

P. Nason, C. Oleari, arXiv:1303.3922

Born-level event generation cut:

- $pp \to \gamma + X$ has coll. divergence at LO $\to$ impose $p_T > p_T^{\text{min}}$
- Influences events at low p_T $\to$ region of interest for thermal γ
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Analytic Born suppression factor:

- Multiplies Born cross section
  - POWHEG ($p_{T,\mathrm{peak}} = 100$ GeV, power $i = 3$):

$$f_{\mathrm{sup.}} = \left(\frac{p_T^2}{p_T^2 + p_{T,\mathrm{peak}}^2} \right)^i$$

  - Approximation of $\Theta(p_T - p_T^{\mathrm{min}})$ (e.g. with $p_T^{\mathrm{min}} = 1$ GeV):

$$f_{\mathrm{sup.}} = \frac{1}{\pi} \left[\arctan[(p_T - p_T^{\text{min}}) \cdot 10^4] + \frac{\pi}{2} \right]$$

- Events then reweighted by $1/f_{\mathrm{sup.}}$, checked independence

Experimental conditions

PHENIX Collaboration at RHIC

Center-of-mass energy: $\sqrt{s}_{pp} = 200$ GeV

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Inclusive photons: [Phys. Rev. C 87 (2013) 054907 and D 86 (2012) 072008]

- $\mathcal{L}$ $(\mathrm{Run}$ $2006) = 4.0$ and 8.0 pb^{-1}
- $p_T^\gamma \in [1; 5]$ and $[5; 25]$ GeV
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Isolated photons: [Phys. Rev. D 86 (2012) 072008]

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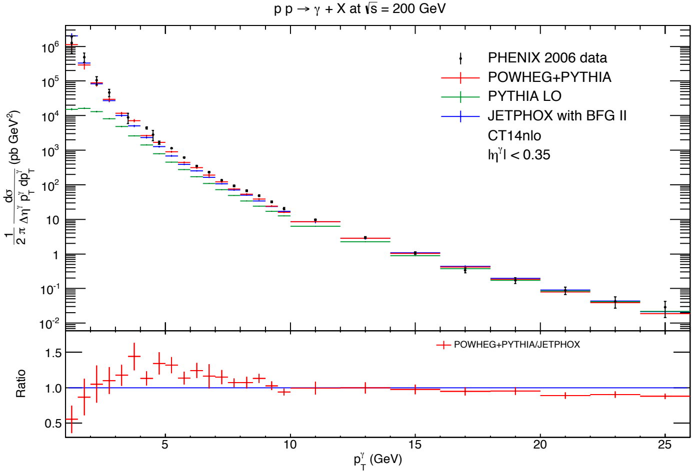
Photons + hadron jets: [Phys. Rev. C 80 (2009) 024908]

- $\mathcal{L}$ (Runs 2005 + 2006) $= 3.0 + 10.7$ pb^{-1}
- Anti-k_T cluster algorithm with $R = 0.4$

Comparison of NLO and POWHEG with PHENIX data

T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.

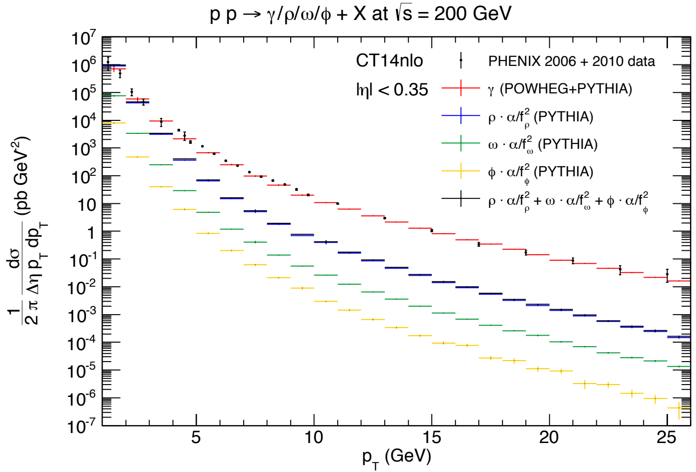


JETPHOX ($\mu = \mu_p = \mu_\gamma = p_T$) too large at low p_T → fragmentation cont.

JETPHOX ($\mu = \mu_p = 0.5\, p_T$, $\mu_\gamma = 2\, p_T$) better [MK, F. König, EPJC 74 (2014) 3009]

Vector meson contributions to prompt photons

T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.

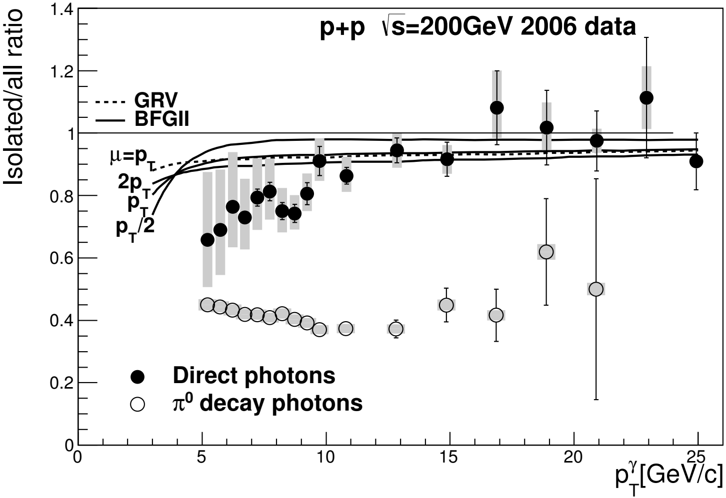


Important at low $p_T \leq 3\,$GeV, dominated by ρ mesons $\rightarrow$ Medium effects?

Factorisation scheme: VMD negligible in DIS$_\gamma$ $\rightarrow$ Resums $\ln[x^2(1-x)]$

Fraction of isolated photons at NLO

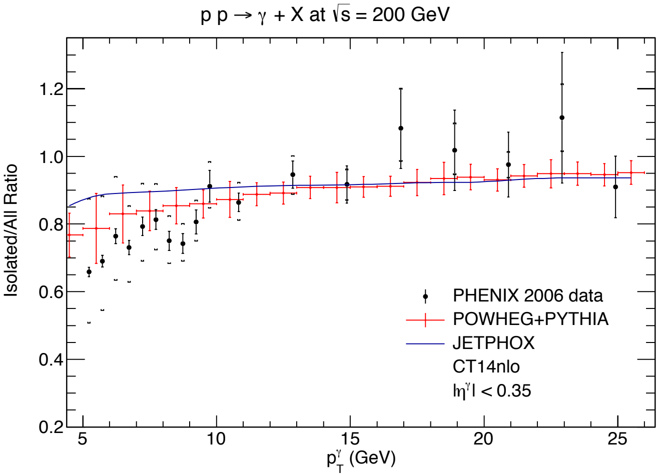
PHENIX Coll., Phys. Rev. D 86 (2012) 072008 (Fig. 13)



NLO too high at small and intermediate p_T for all scale choices

Fraction of isolated photons with POWHEG

T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.

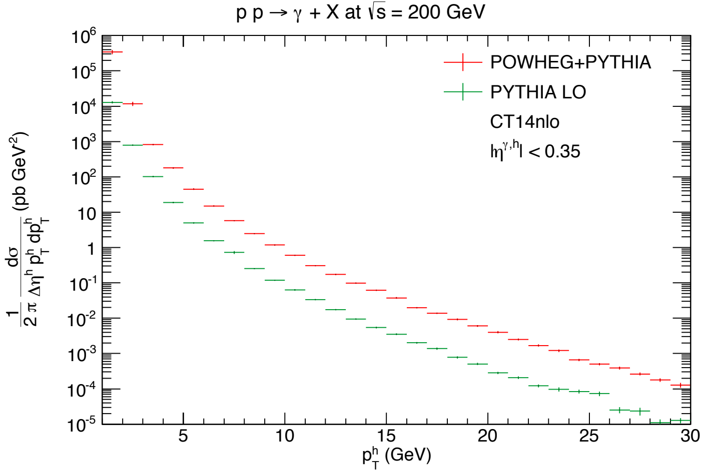


NLO disagreement attributed to quark fragmentation → POWHEG better

Scale uncertainty cancels completely (no fragmentation contribution)

Transverse momentum of associated charged hadron

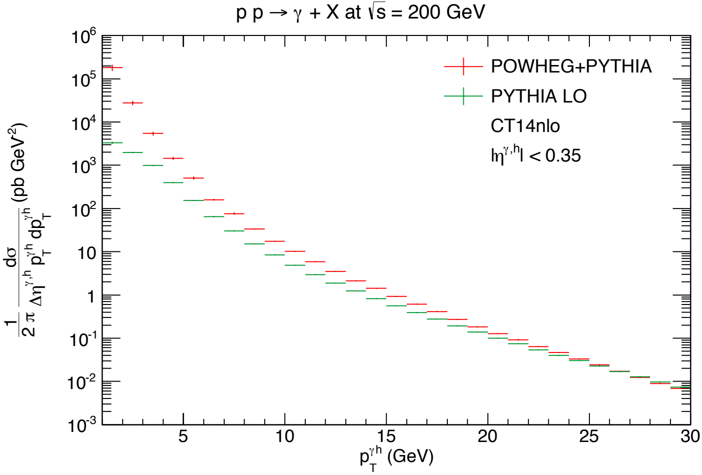
T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.



Energy loss of balancing hadron jet is important observable for QGP
Missing neutral hadrons induce shift in p_T-scale by 20%
K-factor here almost constant: Jet can be balanced by other jets

Transverse momentum balance of photons and hadrons

T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.



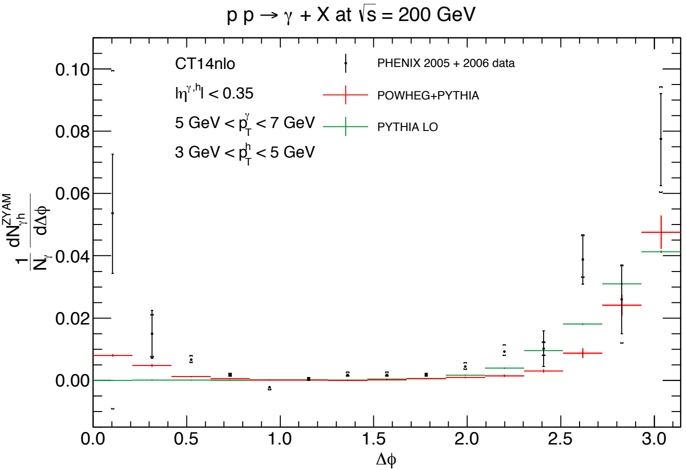
Individual cuts on $p_T^\gamma > 1$ GeV and $p_T^h > 1$ GeV

At $p_T^{\gamma h} \to 0$ NLO diverges, PYTHIA/POWHEG have finite turnover

PYTHIA underestimates absolute cross section in particular at low p_T

Azimuthal correlation of photons and hadron jets

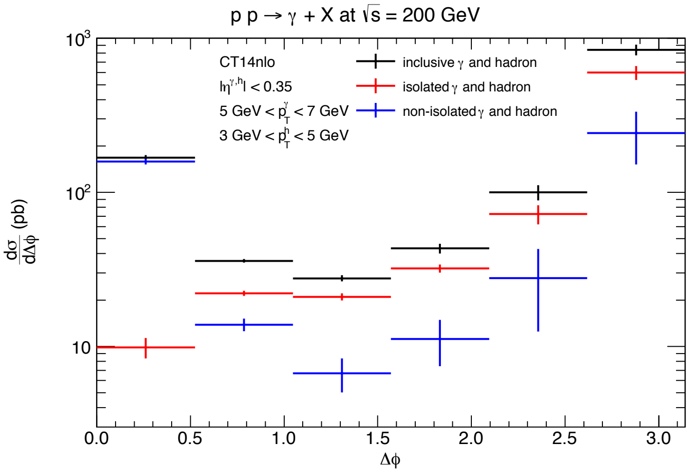
T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.



LO has $\delta(\Delta\phi - \pi)$, NLO vanishes below $\pi/2$, POWHEG follows data
PYTHIA has no "fragmentation" and wrong normalization (not shown)

Contributions of isolated and “fragmentation” photons

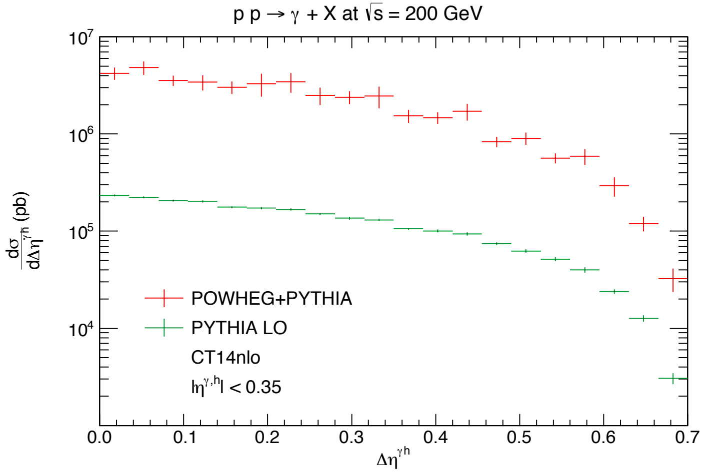
T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.



“Fragmentation” processes mostly collinear ($\Delta\phi \simeq 0$, but also π)

Pseudorapidity correlation of photons and hadron jets

T. Jezo, MK, F. König, arXiv:1610.02275 [hep-ph], accepted by JHEP.



Individual cuts on $p_T^\gamma > 1$ GeV and $p_T^h > 1$ GeV

RHIC detectors limited, but LHC can access low-x region → Saturation?

Conclusion

Motivation:

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Results:

- Improved agreement with p_T spectrum of inclusive photons
- First correct description of isolated photon fraction
- Reliable prediction for photon-jet p_T-balance
- First correct description of photon-jet azimuthal correlation
- Decomposition into isolated and “fragmentation” photons

Outlook

What remains to be done:

- Application to pA and AA collisions
- Study cold nuclear effects with nPDFs
- Implement medium effects (energy loss, hydrodynamics, ...)